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THE EVOLUTION OF SANDY BARRIER FORMATIONS ON THE EAST GIPPSLAND COAST

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Abstract

Two stages of development are recognized in the sandy barriers of the East Gippsland coast: a late Pleistocene stage (the prior barrier and parts of the inner barrier in the Gippsland Lakes region), separated by features of dissection and rearrangement during the Last Glacial phase of low sea level from the Recent stage (the rest of the inner barrier, together with the outer barrier), added during and since the post-glacial marine transgression.

Introduction

The coast of East Gippsland (Fig. 1) is bordered by a series of sandy barrier formations. An **outer barrier**, extending for the whole length of the Ninety Mile Beach, is backed by a narrow tract of lagoons and swamps, and then a line of bluffs, facing seaward, which mark a former cliffed coastline at the margin of a gently undulating plateau of Tertiary and Pleistocene rocks. Between Letts Beach and Red Bluff, the former cliffed coastline recedes behind an embayment of intricate configuration, the East Gippsland embayment, which has been sealed off by barriers to form the Gippsland Lakes. Here, in addition to the outer barrier, there is an **inner barrier** enclosing L. Wellington, L. Victoria, and L. King, and parts of a **prior barrier**, so called because it originated at the head of the East Gippsland embayment before the Gippsland Lakes were enclosed by the inner and outer barriers.

This paper is concerned with the barriers that lie behind the Ninety Mile Beach, rather than with the more complicated pattern of barrier islands in the South Gippsland embayment between Shoal Inlet and Corner Inlet (Fig. 1) which have not yet been studied in detail.

In previous work (Bird 1961a, 1963), it was concluded that the three barrier formations in East Gippsland developed successively on a coast of submergence produced by the post-glacial marine transgression which took place at the end of Pleistocene times, and that they were therefore of Recent (Holocene) age. It was suggested that the prior barrier developed first, at the head of the East Gippsland embayment, when the post-glacial transgression came to an end; the inner barrier then originated as a spit, which grew across the mouth of the embayment and was subsequently widened by progradation on the seaward side. Evidence that the sea stood slightly above its present level when these two barriers formed led to a correlation with the 10-ft higher sea level regarded by Fairbridge (1948, 1961) and others as the maximum attained at the height of the post-glacial transgression. The outer barrier, which generally lies about a mile seaward of the inner barrier shoreline, was attributed to the succeeding 'Recent emergence' when the sea fell to its present level, transposing the zone of barrier formation seaward.

Subsequent work on various kinds of barrier formation, notably on the South Australian and New South Wales coasts (Bird 1965), has led the author to doubt the chronology previously proposed for the East Gippsland barrier sequence. The

FIG. 1—Barrier formations on the East Gippsland coast.

detailed work of Thom (1965) on the coastal barriers of the Port Stephens district in New South Wales, and the more general discussion by Langford-Smith and Thom (1965) of New South Wales barrier formations, prompted a re-examination of the evidence of barrier age in East Gippsland and, as a result of this, a revision of the previous chronology is necessary. It is now suggested that the prior barrier, together with parts of the inner barrier, formed during a late Pleistocene phase when the sea stood at, or a few feet above, its present level; that these barriers were dissected by stream incision and partially rearranged by wind action during a subsequent low sea level phase, evidently the Last Glacial phase; and that the outer barrier, together with part of the inner barrier, developed when the sea returned to its present general level in Recent times.

The evidence for the revised chronology comes mainly from the Paynesville district, in the Gippsland Lakes region (Fig. 2), where the prior barrier is represented by Banksia Peninsula and Raymond Is., the inner barrier by Sperm Whale Head and the Boole Boole Peninsula (including Jubilee Head), and the outer barrier by the dune ridges at Ocean Grange and the Ninety Mile Beach. These form the visible surface tracts of a large mass of generally consolidated and mainly sandy sediment, banked upon a coastal ledge of consolidated Upper Tertiary, and possibly Lower Pleistocene, rock formations in a manner previously described and illustrated (Bird 1963, p. 236). Similar masses of Quaternary deposits have accumulated on many parts of the Australian coast as beach and barrier formations, often enclosing lagoons or tracts of swamp land, and it is now clear that the East

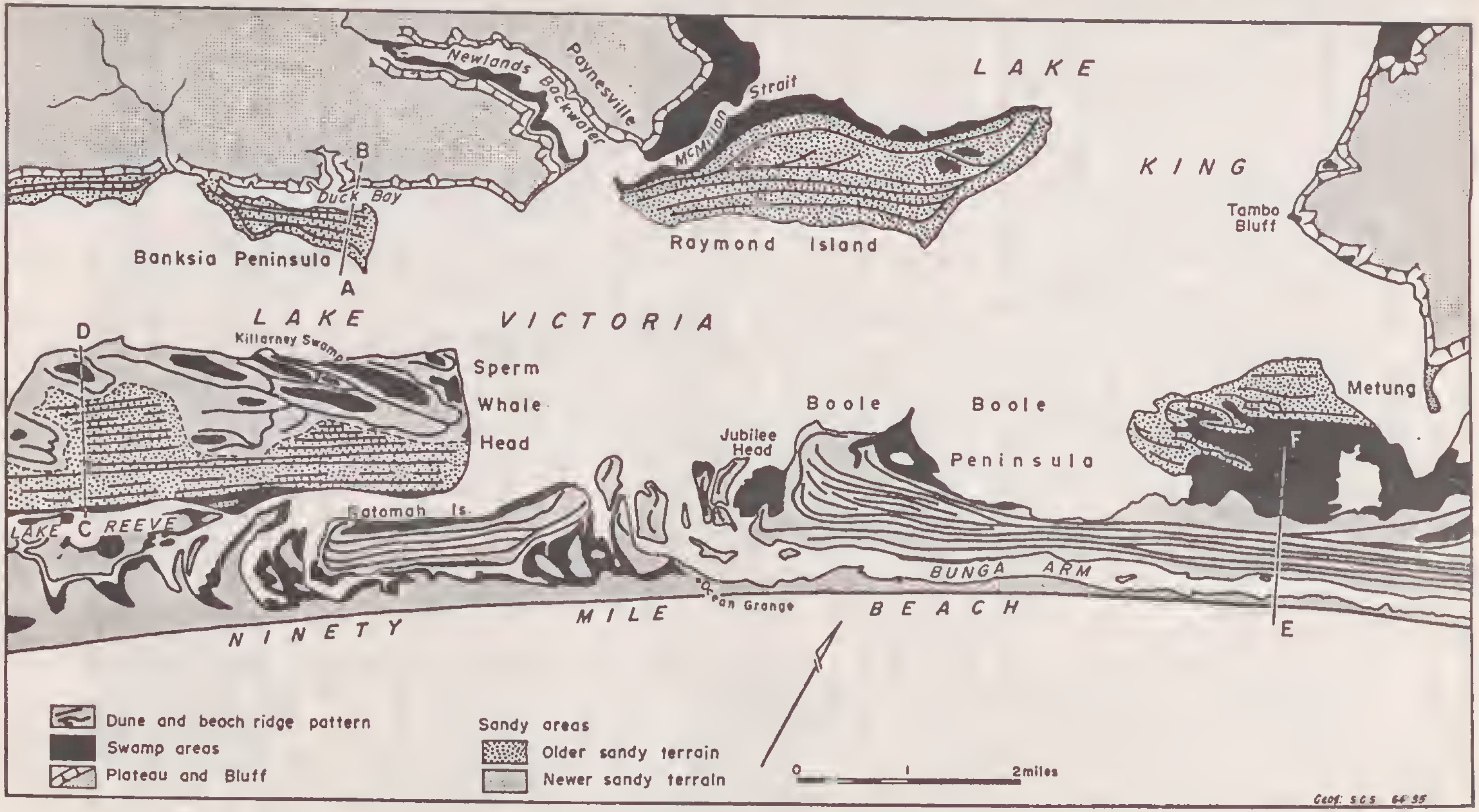

FIG. 2—Barrier formations in the Paynesville district (Boole Boole Peninsula refers to the whole of the inner barrier W. from Metung to Jubilee Head).

Gippsland barriers represent at least two phases of deposition as the sea level rose and fell during Pleistocene and Recent times.

The building of coastal barriers

Sandy barriers of the East Gippsland type were formerly called offshore bars (e.g. Johnson 1919), but modern workers have followed Shepard's (1952) suggestion that the term 'bar' should be restricted to features submerged by the sea for at least part of the tidal cycle, and that depositional forms above normal high tide level should be termed 'barriers'. Johnson (1919) deduced that wave action would build a barrier parallel to the coastline in the offshore zone if the depth of water were suddenly reduced by emergence, due to uplift of the coast or a fall in sea level. Alternatively, a barrier may originate as a spit, elongated parallel to the general outline of the coast, or across the mouth of an estuary or embayment. Both mechanisms of formation require the delivery of sediment to the developing barrier, either eroded or collected from the sea floor and carried shorewards (onshore drifting) or brought along the shore from either direction (longshore drifting), and most barriers have been nourished by a combination of the two processes. Further reference to the problem of barrier initiation will be made after considering the evidence from East Gippsland.

Sandy barriers on the Australian coast are typically surmounted by beach ridges (berms) built parallel to the shoreline by wave action. These have evidently formed successively, as a consequence of the alternation of 'cut' and 'fill' on a shoreline prograding by sand accretion. The beach profile is 'cut' during stormy weather, when short, steep waves scour away the sand, whereas 'fill' takes place during calm weather, when long, low ocean swell delivers sand to the shore and builds up a berm along the length of a beach (Davies 1957). Parallel foredunes may be added when colonizing vegetation traps wind-blown sand on beach ridge foundations (Bird 1960). Successions of parallel beach ridges, with or without surmounting dunes, commemorate the former alignments of a prograding sandy shore, alignments which have evidently been determined largely by the dominant pattern of constructive ocean swell approaching through coastal waters, and often refracted to gently-curved outlines by contact with the sea floor (Davies 1960).

The pattern of parallel beach ridges and dunes may be rearranged during subsequent cycles of 'cut' and 'fill', or interrupted by the development of 'blowouts', which often grow into larger, migrating parabolic dunes, with advancing noses of spilling sand and trailing arms held in place by vegetation. Blowouts and parabolic dunes formed in this way have axes aligned with the onshore resultants of wind action, as determined from directional wind vector diagrams (Jennings 1957). Their pattern interrupts and displaces pre-existing parallel beach ridges and dunes. Blowouts are generally initiated where the retentive cover of dune vegetation is damaged or destroyed, particularly where a foredune is truncated at the back of the shore by storm wave action, laying bare a cliff of crumbling sand in which the wind carves out a hollow, spilling some of the sand landward. Blowouts may also form where the edge of a vegetated dune is cut back by river or tidal scour, or where the vegetation cover is weakened by fire, overgrazing, aridity, or excessive trampling by animals or man. If the initiating factor, whether erosional or ecological, ceases to operate, a blowout or a parabolic dune may be arrested and stabilized by recolonizing vegetation.

On the East Gippsland coast the barriers consist mainly of quartz sand, with only a small proportion of shelly material. The proportion of carbonates in the sand on the Ninety Mile Beach rarely exceeds 10 per cent, and it is probable that the beach ridges and dunes of the barriers here were built from similar material. The characteristic succession of soil and vegetation features seen on transects across parallel beach ridges and dunes of quartzose sand leads to the development of deep podzol profiles and vegetation communities dominated by heath species on the oldest sites (Burges and Drover 1957; Turner, Carr, & Bird 1962). The leaching of carbonates from the upper layers of a newly-built beach ridge or dune by percolating rainwater is followed by the removal of the iron oxides that give fresh sand grains their yellow colouring, and organic matter derived from dune vegetation is washed down through the sand and accumulates, together with some of the leached iron oxides, as an illuvial horizon of lightly-cemented sandrock ('coffee rock'), generally close to the level of seasonal water-table fluctuations. This is essentially the process of podzolization and the end-product, a deeply-leached 'A' horizon over an illuvial sandrock 'B' horizon, is termed a ground-water podzol (Stephens 1962). The process is accompanied by, and to some extent depends on, a vegetation succession that starts with the grasses (chiefly *Festuca littoralis, Spinifex hirsutus*, and the introduced *Ammophila arenaria*) that trap wind-blown sand to build foredunes at the back of a beach. Growing foredunes remain grassy, but once a newer foredune develops, cutting off the supply of wind-blown sand, growth ceases and the grasses are replaced by 'dune scrub' communities, dominated by *Leptospermum laevigatum*, with the coastal banksia tree *Banksia integrifolia* common. Under dune scrub the sand is leached to depths of 2-3 ft, the surface sand having a pH value of 5·5 to 6·5 (compared with about 8·0 for fresh dune sand), with no shell material remaining. On the older beach ridges and dunes, scrub is replaced by 'dune woodland', with *Eucalyptus viminalis* the dominant tree, and an undergrowth of bracken (*Pteridium esculentum*). Here, the dune sand may be leached to depths of more than 10 ft, the leached zone being underlain by a layer stained brown by the accumulation of organic matter and iron oxides, but not yet a firm coffee rock. Surface sand has pH values in the range 5·0 to 6·5 and, as acidity increases, the coastal banksia gives place to the saw banksia, *Banksia serrata*. This tree shares dominance with *E. viminalis* on the oldest beach ridges and dunes, where 'heath woodland' is developed, the bracken undergrowth giving place to communities of heath shrubs (e.g. *Epacris impressa, Hibbertia acicularis, Astroloma humifusum, Amperea xiphoclada*, and the localized dotted heath-myrtle, *Thryptomene miqueliana*, abundant on Sperm Whale Head). Locally, the heath is almost treeless. The soils are profoundly leached and strongly acid (pH considerably below 4·0 at the surface), with a firm coffee rock horizon at depth.

The succession of soil and vegetation features across parallel beach ridges and dunes clearly represents an age sequence from the youngest, newly developed on a prograding shore, to the oldest, towards the landward margin. Where blowouts and parabolic dunes have developed, the transverse age sequence of soil and vegetation features has been interrupted.

The prior barrier

The prior barrier, traceable from the N. side of L. Wellington eastwards to Banksia Peninsula and Raymond Is., originally developed in front of a cliffed coastline at the head of the East Gippsland embayment. The probable configuration at this stage is shown in Fig. 4A, with Tom's Ck flowing into a lagoon behind the W. half of the prior barrier, and the outlet from Newlands Backwater deflected north-eastwards, through McMillan Strait, to open into what is now the N. part of L. King. This reconstruction is based on the pattern of beach ridges which form the ground-plan of the dissected remnants of the prior barrier. Best preserved on

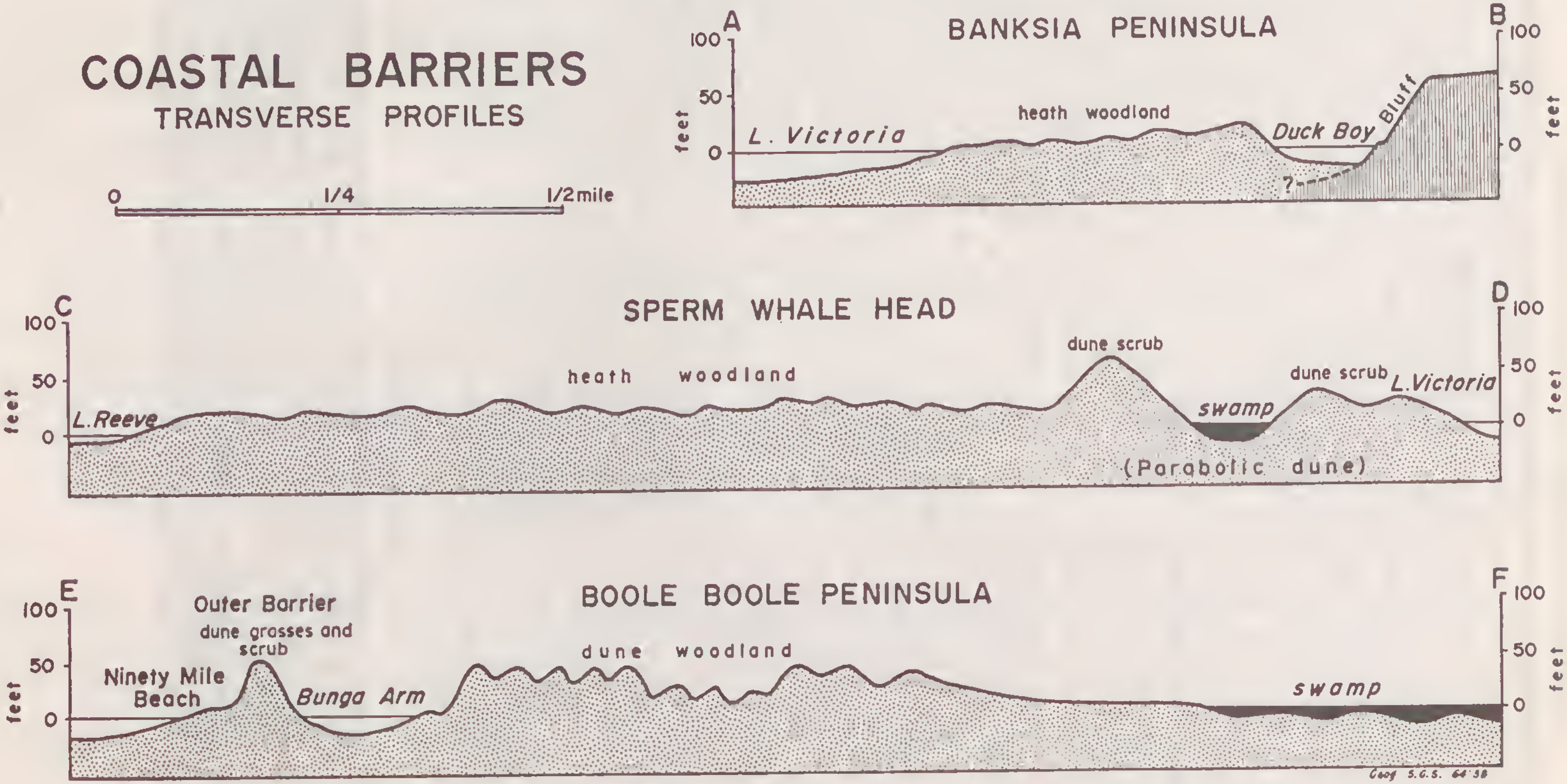

FIG. 3—Transverse profiles of barrier formations shown on Fig. 2. AB, prior barrier at Banksia Peninsula. CD, inner barrier at Sperm Whale Head. EF, outer barrier near Ocean Grange and inner barrier at Boole Boole Peninsula.

Banksia Peninsula, these run roughly parallel to the bluffs that lie behind them. Their crests are spaced at intervals of 100-150 yds, and their amplitude (from crest to swale) is 5-15 ft. The swales stand generally 5-10 ft above the calm-weather level of L. Victoria, the lake level being approximately equivalent to mean sea level in Bass Strait. In section (Fig. 3AB), the topography is subdued and there is a slight seaward fall. The sand has been thoroughly leached, and a well-defined coffee rock layer is found about 5 ft beneath the swales and up to 10 ft beneath the crests; it is horizontal or gently undulating and a little above calm-weather lake level. Heath woodland vegetation is dominant.

These features of morphology, soil, and vegetation suggest that the prior barrier is of considerable antiquity, and the slightly elevated swales may indicate that sea level at the time of prior barrier formation stood a little higher than it does now. But there has been much subsequent dissection. S. of Paynesville, a broad strait has been cut through the prior barrier, separating Raymond Is. from Banksia Peninsula, and wide embayments have been formed intersecting the barrier on the N. shore of L. Victoria. In addition, there are other outgrowths in the form of recurved spits and cuspate forelands, the largest of which has grown southwards to separate L. Wellington from L. Victoria. Parts of the sandy terrain lying N. of these lakes are therefore of comparatively recent origin; several of the cuspate forelands on the N. shore of L. Victoria are still being enlarged by sand accretion. The shores of Banksia Peninsula and Raymond Is. also show marginal depositional features of more recent origin added to the dissected remnants of the original prior barrier.

The inner barrier

The inner barrier is of composite origin and has had a complex history. The ground-plan of beach ridges and dune ridges at its SW. end, S. of L. Wellington, shows that it originated as a recurved spit which was prolonged intermittently north-eastwards across the mouth of the embayment, and afterwards widened by the addition of successive parallel beach ridges and low foredunes on the seaward side (Bird 1963, Fig. 1). The parallel ridges are well preserved on Sperm Whale Head (Fig. 2), where their dimensions and spacing (Fig. 3CD) are similar to those on Banksia Peninsula. The swales are again 5-10 ft above calm-weather lake level, and there are deep podzol profiles, with coffee-rock at depth, and a heath woodland vegetation, all suggestive of an age comparable with that of the prior barrier. It appears that the recurved spit, which became the first inner barrier, grew across the mouth of the embayment soon after the prior barrier had formed, enclosing a lagoon system on the site of the present Gippsland Lakes (Fig. 4B).

The inner barrier has been much modified since it first formed. The pattern of parallel beach ridges and dunes has been partially rearranged into a group of parabolic dunes which migrated eastwards until they became stabilized in their present positions. These are well displayed on Sperm Whale Head (Fig. 2), where the older beach ridges, low and widely-spaced, are in sharp contrast with the adjacent parabolic dunes which are locally more than 90 ft high. Soil profiles on the parabolic dunes are only a few feet deep compared with the ground-water podzols on the undisturbed beach ridges, and the *Leptospermum laevigatum* scrub and dune woodland on the parabolic dunes is in sharp contrast with the heath woodland on the older beach ridges. The evidence of soils and vegetation therefore confirms the idea that rearrangement into parabolic dunes took place after the original formation of low and widely-spaced beach ridges on the inner barrier, and came to an end when a vegetation cover became re-established on the parabolic dunes.

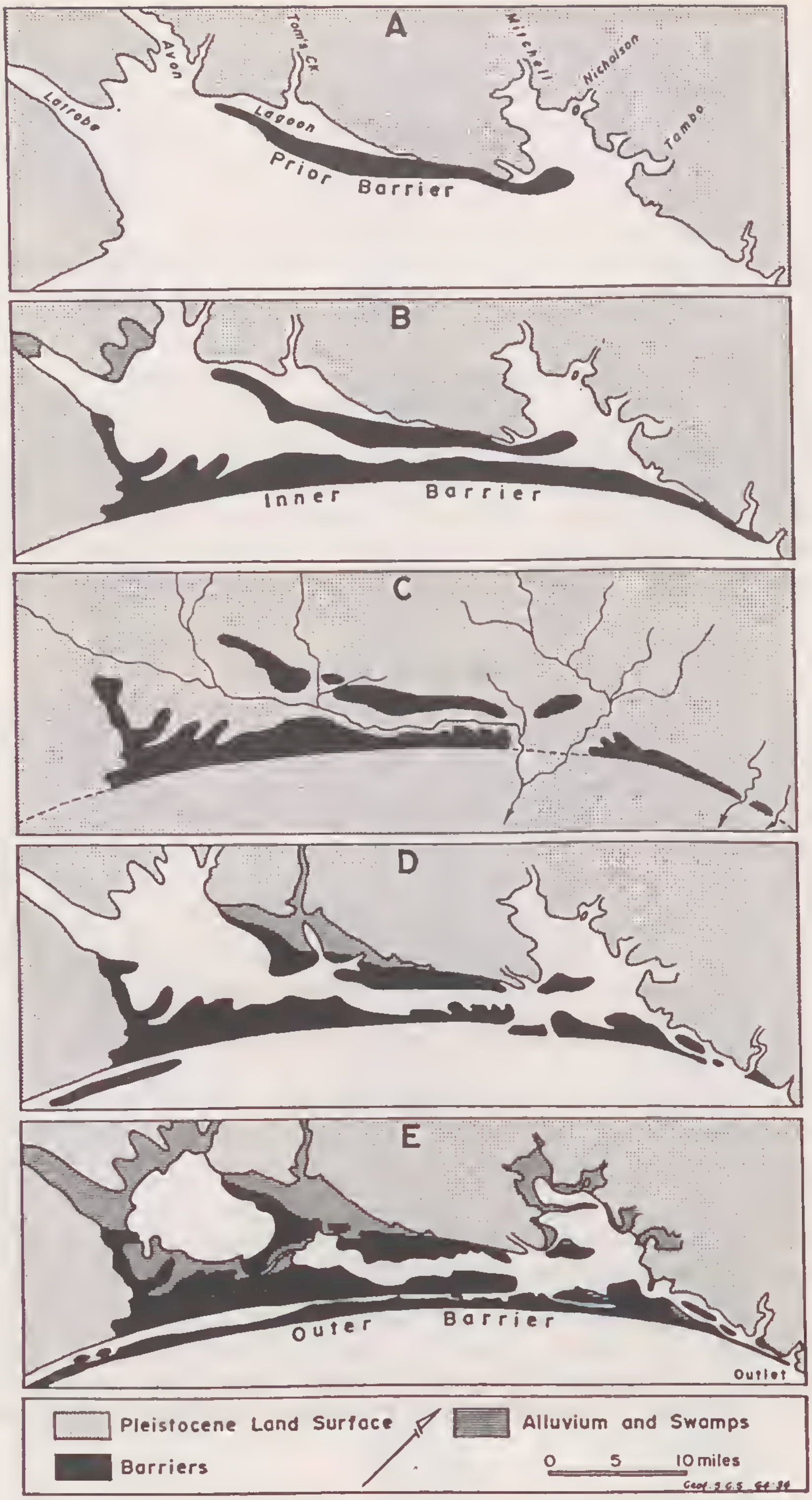

FIG. 4—Evolution of barrier formations in the Gippsland Lakes region.

The swales that lie between the trailing arms of these parabolic dunes are now swampy flats, occupied by lagoons after heavy rain or when flood waters invade from L. Victoria. They generally have a central unvegetated clay plain, surrounded by zones of salt marsh and swamp scrub (mainly *Melaleuca ericifolia*) vegetation; Killarney Swamp on Sperm Whale Head, shows these typical features. Borings have shown that the swamp deposits, chiefly organic clays and silts, extend to a depth of at least 20 ft here, and so the deflated sandy floor of the parabolic dune must lie considerably below present lake level and well below present sea level. From this evidence it is concluded that the parabolic dunes developed at a time when the sea stood at a lower level than it does now, that is before the post-glacial marine transgression brought the sea to its present general level. This transgression flooded the swale to form a narrow lagoon, which has since been filled to calm-weather lake level by accumulation of swamp deposits. It is inferred that, during the Last Glacial phase of low sea level, late in Pleistocene times, the basin now occupied by L. Wellington and L. Victoria drained out, and that the Latrobe and Avon Rivers, together with other tributaries, extended their courses along the emerged furrow and found a way out across the sea floor to the low sea level. The broad gap in the inner barrier E. of Sperm Whale Head probably marks the site where river drainage escaped at this stage. The prior barrier was now breached by the outflow from Tom's Ck, which then became incised into a lacustrine plain which is the emerged floor of the lagoon mentioned previously in the section on the prior barrier, and from Forge Ck (Newlands Backwater) which found a southward outlet between Banksia Peninsula and Raymond Is. L. King must also have drained out, so that the Mitchell, Nicholson, and Tambo Rivers flowed across its floor and out through the broad gap in the inner barrier. The configuration at this stage is shown in Fig. 4C. The inner side of the inner barrier was probably cut back, with initiation of parabolic dunes, as the result of scour by the extended Latrobe River flowing along what is now the floor of L. Victoria.

During the succeeding marine transgression, the rising sea flooded back into the lagoon basins and the outer barrier was built up as an additional seaward rampart enclosing the Gippsland Lakes. The swales of parabolic dunes on Sperm Whale Head were flooded and, as swamps began to develop in them, the dunes, no longer activated by wind-drifted sand, became colonized by vegetation and stabilized in their present outlines. By this time, however, an additional change had occurred in the inner barrier, for the E. half (the N. portion of Boole Boole Peninsula) stands at a lower elevation than the W. half, Sperm Whale Head. Low, widely-spaced parallel ridges, similar to those on Sperm Whale Head, are still traceable on the N. portion of Boole Boole Peninsula and the soil and vegetation features are also similar, but the intervening swales stand at or below present calm-weather lake level, compared with an elevation of 5-10 ft on Sperm Whale Head. The swales are occupied by tracts of swamp land, bordered by salt marsh and swamp scrub vegetation (Bird 1962), but eastwards (S. of Metung) they widen and coalesce as the beach ridges vanish beneath a broad swamp. Traced by probing, they remain widely-spaced and parallel (Fig. 3EF, right-hand portion). This evidence suggests that the inner barrier has been tilted transversely, either by tectonic elevation of the section farther W., or because of subsidence of Boole Boole Peninsula, which could result from compaction of underlying deposits, such as compressible peats, interbedded at depth. The immediate consequence is that the younger foredunes of the outer barrier, which farther W. developed a mile or so seaward of the inner barrier shoreline, have been built **on to** the S. part of Boole Boole Peninsula (Fig. 4D); although geographically part of the inner barrier, these foredunes are undoubtedly of Recent origin, having developed as the post-glacial transgression submerged the S. margin of the older barrier. There is a succession of high (20-30 ft) and closely-spaced (30-50 yds) parallel dunes (Fig. 3EF), with dune woodland on soils that are leached to about 10 ft, but with no development of true coffee rock. The parallel dunes extend W. to Jubilee Head, a complex recurved spit on the E. side of a 'tidal delta' of shoals, low islands, and channels, which marks a gap in the barrier system open to the sea until very recently. On the W. side of this gap there is a matching recurved spit at Rotomah Is. and it is probable that, at one stage, this section of the barrier extended farther to the SW. The S. margin of Boole Boole Peninsula has an extremely fresh appearance and was clearly a beach, open to the sea, until the outer barrier developed in front of it.

The outer barrier

Westwards from Sperm Whale Head, the outer barrier stands about a mile seaward of the S. shore of the inner barrier, separated from it by L. Reeve, a tract of sandflats, salt marshes, and shallow lagoons. The Ninety-Mile Beach forms its seaward margin and it is surmounted by a series of high (20-80 ft) and closely-spaced (30-50 yds) parallel dunes. At Ocean Grange there are two of these but, westwards, the number increases to a maximum of thirteen at Letts Beach, where the vegetation on parallel dunes shows the early stages in succession from grasses on the unleached sand of newly-built foredunes to dune scrub and woodland on the moderately leached sand of the inner ridges. Depth of leaching increases from dune crest to dune crest on landward transects away from the Ninety Mile Beach, confirming that these dunes were built successively on a sandy shore that has prograded. The oldest, on the landward side, has been leached to a depth of about 5 ft but, although the underlying sand is stained reddish-brown, the accumulation of down-washed organic matter and iron oxides has not yet reached the status of coffee rock. The absence of heath vegetation and the rarity of the saw banksia (*B. serrata*) on the dunes of the outer barrier support the idea that these parallel dunes are of no great age.

The initiation of the outer barrier is not easily explained, for it does not conform exactly with either of the usual explanations of barrier formation mentioned previously. As the S. shore of the inner barrier at Sperm Whale Head shows no sign of any recent modification by the waves of the open sea, the outer barrier must have come into existence during the later stages of the post-glacial marine transgression as the sea approached its present general level. The pattern of parallel dunes yields a little more evidence, for the multiple foredunes at Letts Beach indicate a section of the barrier that developed at an early stage as a barrier island. Traced laterally, the inner dunes curve away successively to recurved terminations in L. Reeve, the number of parallel dunes diminishing in this manner north-eastwards and south-westwards from Letts Beach. The barrier island initiated offshore at Letts Beach was evidently elongated north-eastwards and south-westwards and prograded to take up the present alignment of the Ninety Mile Beach. South-westwards, the growth of the outer barrier cut off a formerly cliffed coastline at Seaspray, and continued to its present termination as a recurved spit S. of Woodside, with Shoal Inlet on the inner flank. Growth to the NE. was irregular, for there are a series of curved channels leading from L. Reeve into the back of the outer barrier W. of Rotomah Is. (Fig. 2), which testify to the former existence of gaps in the barrier, diverted north-eastwards by longshore drifting before they were finally sealed off. The features are similar to those described by Lucke (1934) from coastal barriers in the vicinity of Barnegat Inlet, New Jersey, where gaps in the barriers have migrated and closed under the influence of longshore drifting. Current action in these deflected channels evidently truncated the south-westward extensions of Rotomah Is., fragments of which are traceable in the sandy terrain on the S. side of L. Reeve. The continued growth of the outer barrier north-eastwards eventually outflanked the gap between Rotomah Is. and Jubilee Head, Bunga Arm persisting as an outlet channel that also suffered north-eastward diversion and final closure. The story was completed by the extension of the outer barrier as far as Red Bluff, the Cunninghame Arm at Lakes Entrance being the last of the deflected outlets from the Gippsland Lakes, still active at the time of discovery in 1839 (Fig. 4E). The cutting of an artificial entrance through the outer barrier at Lakes Entrance in 1889 stabilized the outlet from the Gippsland Lakes and led to the sealing of the former natural outlet farther E. (Bird 1961b).

The initiation of the outer barrier in the vicinity of Letts Beach may have been a consequence of an exceptionally abundant nearshore sand supply on this section of the coast, or it may have been prompted by localized tectonic uplift of the land. It is perhaps significant that Letts Beach lies upon the seaward continuation of the Deadman's Hill ridge, an anticlinal area of Tertiary rocks in a region that has been subject to tectonic deformation during Quaternary times (Boutakoff 1955); its uplift could still have been in progress when the post-glacial marine transgression came to an end and, indeed, may have been part of the movement which gave the inner barrier a lateral tilt. Elongation and progradation of the barrier island initiated here resulted from the continued delivery of large quantities of sand to the coast, and sand has been spread along the shore in either direction by the action of waves and associated currents.

In these terms, it is not necessary to invoke an episode of general 'Recent emergence' to explain the initiation of the outer barrier, although the possibility of localized emergence due to uplift of the land has been mentioned. The view that the post-glacial marine transgression rose to a higher level about 4,000-6,000 years ago and then dropped back to its present stand has been widely accepted by Australian coastal geomorphologists following Fairbridge (1948) and others, but it has been criticized, notably by Shepard (1961) and Russell (1963), on the grounds that the evidence is not world-wide in the manner required for a eustatic oscillation of sea level. The widely-reported evidence of Recent emergence on the Australian coast may result from uplift of certain sections of the coast late in Quaternary times; on the East Gippsland coast, Recent emergence, if it has occurred at all, has evidently been localized in a manner suggestive of tectonic uplift.

Present-day shoreline erosion

The long-continued progradation of the sandy shoreline of East Gippsland appears to have come to an end at least temporarily, for, during the last few decades, 'cut' has exceeded 'fill' along the Ninety Mile Beach and new foredunes have not developed. Instead, the outer edge of the youngest dunes has been truncated by wave attack and blowouts have been initiated, with sand spilling landwards across the outer barrier. NE. of Ocean Grange this erosion may soon breach the outer barrier and reopen Bunga Arm as a natural outlet from the Gippsland Lakes.

Evidence of a very recent phase of shoreline erosion is widespread on the sandy shores of SE. Australia, and has been attributed to a renewed eustatic rise of sea level, perhaps accompanied by increasing storminess in coastal waters (Davies 1957). An alternative suggestion is that the erosion is due to a reduction in sand supply in coastal waters, the consequent steepening of the offshore profile allowing more powerful wave action to attack the shore (Langford-Smith & Thom 1965), but this reduction is probably associated with either or both of the factors noted by Davies. The absence of cliffing on the foredunes preserved behind the sandy forelands that have developed since 1889 alongside the protruding stone jetties at Lakes Entrance places the onset of erosion within the past century (Bird 1960), and within the period for which world-wide tide gauge analyses suggest a secular eustatic rise of sea level (Valentin 1952).

The source of the sand

The traditional explanation of the origin of the East Gippsland barriers is that sand has been swept north-eastwards along the coast from the vicinity of Wilson's Promontory by a powerful ocean current (Gregory 1903), and that this was a sequel to the foundering of the 'land bridge' that formerly extended across Bass Strait between Tasmania and the mainland (Hall 1914), but these hypotheses cannot be accepted in the light of modern knowledge of coastal evolution. The 'powerful ocean current' does not exist, and the weak ebb-and-flow tidal currents which occur off the Ninety Mile Beach cannot have moved much sand, but sand is transported north-eastwards along the Ninety Mile Beach as the result of longshore drifting by waves and associated currents generated when strong winds drive in waves from the SW., and in the opposite direction when the waves come in from an easterly direction. As the westerly winds are prevalent, the drift to the NE. probably exceeds that to the SW. The balance is a fine one, however, for the similar scale of beach accumulation on either side of the protruding stone jetties at Lakes Entrance indicates that similar quantities of sand have arrived here from both directions (Bird 1961b).

There is little evidence that a major source of sand existed formerly in the vicinity of Wilson's Promontory and, as the plunging coastal slopes of resistant granite have not been cliffed by marine erosion since the sea attained its present level, they cannot have produced large quantities of sand. In any case, the barriers have not grown north-eastwards from Wilson's Promontory, for the prior and inner barriers originated in the East Gippsland embayment about 50 miles NE. of the Promontory, and the outer barrier terminates in a recurved spit which has grown south-westwards **towards** Wilson's Promontory. The suggestion that barrier formation was linked with the making of Bass Strait is ruled out by the evidence that Bass Strait has existed intermittently since late Tertiary times during the rise and fall of Pleistocene eustatic oscillations of sea level (Jennings 1959a); it was finally revived by the post-glacial marine transgression, and was already in existence when the sea rose towards the East Gippsland coast during the later stages of that transgression. More generally, there seems no need to link the formation of the East Gippsland barriers with the origin of Bass Strait, since there are similar barriers on the New South Wales coast, and in Encounter Bay on the South Australian coast, which can bear no relation to the formation of straits or to any such changes in adjacent coastal configuration.

The origin of the East Gippsland barriers has evidently depended more on the onshore drifting of sand and the effects of refracted ocean swell in supplying sediment and determining shoreline alignments than on longshore drifting of coastal sand. Longshore drifting has played a part in the growth and shaping of the barriers, but the bulk of the material has been eroded or collected from the sea floor and carried shorewards. This is most obvious in relation to the outer barrier, which was prograded by sand accretion even after it had developed in front of the cliffed coasts and river mouths which might otherwise be regarded as possible sources of sand for barrier construction. The sand evidently came from deposits that were previously laid down on the sea floor as barriers or dunes when the sea withdrew to a low level during the Last Glacial phase. There is now little evidence of these depositional forms, for the sea floor off the Ninety Mile Beach was smoothed over by wave action during the succeeding marine transgression, when sand was collected and carried shoreward to build and nourish the outer barrier, but, off Flinders Is., Jennings (1959a) has identified submarine ridges of uncertain origin which could be relics of submerged barrier or dune formations that have survived destruction by the rising sea. The formation of barriers off the present shoreline during a low sea level phase, and their subsequent destruction by the waves of a transgressing sea to provide sand for the building of newer barriers, has also been postulated by Hails (1964) to explain certain features of beaches and barriers on the New South Wales coast. The concept of landward sweeping of sea floor sediments during the post-glacial marine transgression helps to explain many aspects of Australian coastal beach and barrier formations.

Conclusions

The revised chronology now presented turns on the recognition that certain features of rearrangement and dissection of the prior and inner barriers in the Gippsland Lakes region originated when the sea stood at a lower level, preceding the post-glacial marine trangression. This was evidently the Last Glacial phase when sea level is believed to have fallen at least 300 ft (Shepard 1961). The original formation of the prior and inner barriers is therefore placed back in a late Pleistocene interglacial (or interstadial) phase when the sea stood at or slightly above its present level, and the addition of the outer barrier took place in Recent times, during and after the post-glacial marine transgression. Certain features of the barriers suggest the influence of Quaternary tectonic deformation of this section of coast: the evidence of transverse tilting since the original formation of the inner barrier, and the possibility of uplift as a means of initiation of a section of the outer barrier as a distinct feature offshore in the vicinity of Letts Beach.

In terms of this chronology, it is suggested that barriers which have been built of quartzose sand on the coasts of SE. Australia are likely to be of Pleistocene origin where they show deep podzolic profiles with true coffee rock at depth and a heath or heath woodland vegetation, but of Recent origin where they show evidence of incipient podzolization without true coffee rock and a vegetation of grasses, scrub or dune woodland without heath communities. This is essentially the distinction made by Jennings (1959b) in recognizing Old Dunes of late Pleistocene age and New Dunes of Recent age on the coasts of King Is. The distinction is less clear where the parent sand material is strongly calcareous, as on the W. coast of King Is., the W. side of Wilson's Promontory, and much of Australia's S. and W. coast, where a higher base status reduces the rate of podzol formation and succession to heath vegetation on dunes and beach ridges lithified as calcarenites. On the other hand, if the quartzose sands are extremely poor in original shell content, as on parts of the coast of Wilson's Promontory, dunes and beach ridges of Recent origin may show the advanced podzolic profiles and associated heath communities that are elsewhere typical of older coastal sand deposits.

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